

# The National Energy Technology Laboratory

## Sensors and Controls Workshop



Robert Romanosky, Advanced Research Product Manager



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# Workshop Objectives

- **Afford an opportunity for participation in the Sensors and Controls Program planning process**
  - Obtain perspective of industry, academia and government
  - Assist in formulating a roadmap for the Fossil Energy Sensors and Controls Program
- **Review and update the existing Vision 21 Sensors and Controls Roadmap**



# The How of Workshop

- Attendees will be divided into groups, according to technology needs
- Discussion of sensors and controls needs in each area will be discussed and formulated
- Prioritization of needs will be determined from groups' perspective
- Presentation of groups' findings will be presented to workshop
- Workshop findings will be incorporated into a fossil energy sensors and controls roadmap



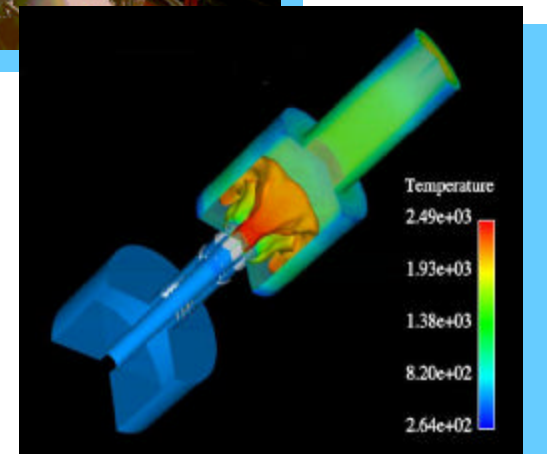
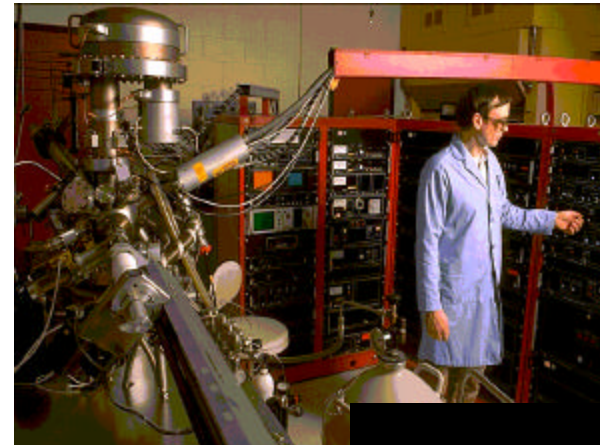
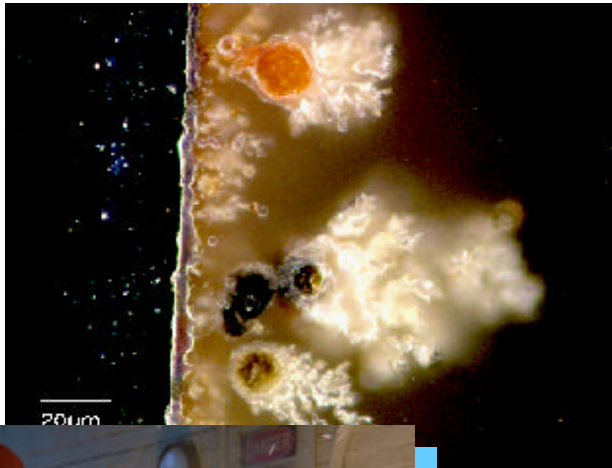
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# Workshop Product

- **Produce document defining the sensors and controls R&D needs in each of the technology areas**
  - Prioritize the R&D needs associated with each technology area
- **Provide data needed for the next step in roadmapping the Fossil Energy Sensors and Controls area**
- **Update Vision 21 sensors and controls roadmap**



# Advanced Research Program



# Advanced Research - Power Systems

*Ingenuity, innovation and implementation*

## Goal

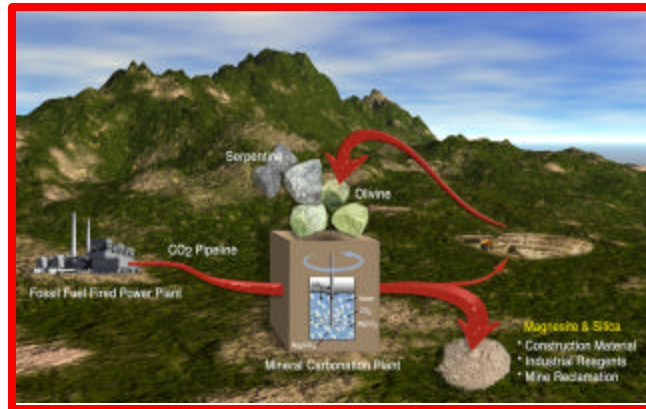
- Extend state of knowledge in fossil energy technology by supporting development and deployment of innovative systems capable of improving efficiency and environmental performance while reducing costs



*Advanced materials consortium for ultra- supercritical power plants -  
NETL/ORNL/EPRI/CURC*

## Uniqueness

- Bridge gaps between fundamental science and advanced engineering to overcome technical barriers encountered by R&D programs
- Stimulate advanced research in new directions--explore innovative concepts to enhance pace of fossil energy technology development



*Mineral carbonation-  
NETL/ARC/LANL/ASU*



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# AR Program Areas

- **Coal Utilization Science (CUS)**
- **Materials**
- **Advanced Metallurgical Processes**
- **Bioprocessing**
- **University Coal Research (UCR)**
- **Historically Black Colleges and Universities/ Other Minority Institutions (HBCU/OMI)**
- **SBIR/STTR**



# Advanced Research - Power Systems

## **Near-term Emphasis**

- Sensors and controls
- Advanced materials program development
- Virtual simulation for Vision 21 plants
- CO<sub>2</sub> mineral sequestration
- Bio-process research (sequestration, hydrogen, remediation)
- Align UCR to Vision 21 Program



# **Advanced Research Plans for FY02**

- **Initiate NETL Instrumentation, Sensors and Controls Systems (ISCS) Program through a solicitation to investigate and develop sensors and controls systems that crosscut all Product Lines for advanced power system market penetration**
- **Collaborate with NETL Materials Program to develop low-cost in situ sensors for advanced IGCC, other gasification and combustion systems**
  - **Develop sensors in parallel with gasifier and combustion technologies (instead as an afterthought)**
- **Development of reliable, robust, long-term durable and extremely low-maintenance front-end conditioning systems for established detection systems of selected continuous emissions monitors (CEMs)**



# ADVANCED RESEARCH PROGRAM

## BUDGET TRENDS (\$Million)

<u>PROGRAM</u>	<u>FY 2000</u> <u>APPR</u>	<u>FY 2001</u> <u>APPR</u>	<u>FY 2002</u> <u>REQ</u>
<b>AR</b>			
• Coal Utilization Science	6.3	6.3	6.3
• Bioprocessing	1.4	1.4	1.4
• University Coal Research	3.0	3.0	3.0
• Materials	7.0	7.0	7.0
• Center of Excellence	0.0	3.0	3.0
<b>Total AR</b>	<b>17.7</b>	<b>20.7</b>	<b>20.7</b>
<b>Advanced Metallurgical Processes</b>	<b>5.0</b>	<b>5.2</b>	<b>5.2</b>
<b>TOTAL ADVANCED RESEARCH*</b>	<b>22.8</b>	<b>30.1</b>	<b>26.7</b>

\*Does NOT include: Coal Export Technology; Environmental Activities; Technical and Economic Analysis; International Program Support; International Capacity Building; HBCU, Advanced Fuel Cell Research.



# Why Sensors and Controls

- **Fossil energy is critical to U.S. economy: 85% of energy use in the U.S. is supplied by fossil fuels; 53% of electric power is generated by coal.**
- **Deregulation demands lower electricity cost and improved grid connectivity.**
- **Infrastructure protection requires better monitoring.**
- **Increasing concerns on global climate change requires significantly higher efficiency and substantially lower carbon emissions.**
- **Environmental concerns mandate higher reductions in pollutant emissions.**



# How Do Sensors and Controls Help?

- **BENEFITS:** Improve reliability, reduce operating and maintenance costs, enhance grid connectivity, enhance efficiency, reduce CO<sub>2</sub> and other emissions, and support economic development.
- **COSTS:** Cost less than the capital intensive equipment used in power generation.
- **PONTENTIAL:** Compared to automobiles, airplanes, and defense applications, the sensors and instrumentation used in power plants appear to have room for improvement, indicating R&D opportunities exist.



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# Strategies

- **Identify useful technologies**
- **Identify desired measurement**
- **Establish applicability of new technologies for the quantities to be measured (find a match)**
- **Identify key players**
- **Assemble the experts and stakeholders to discuss the findings**
- **Identify the key areas to start**



# **Desired Measurement (temperature, pressure, composition, monitoring and control)**

- Online gas species ( $O_2$ , CO,  $NO_x$ ,  $SO_2$ , etc) and their distribution
- Ash/slag deposition and composition
- Monitoring ash deposition and filter status for gasification
- Nondestructive measurement for structural components
- On-line structural monitoring
- Intelligent power transmission and distribution through grid
- Temperature and pressure
- Trace element
- Wireless data transmission
- Process control and optimization



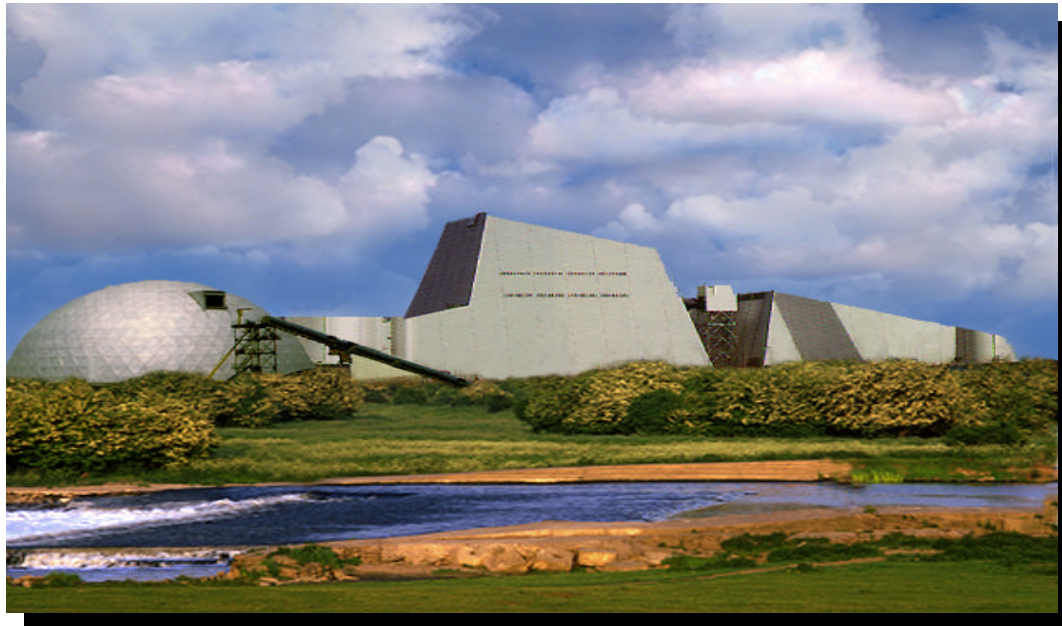
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# Challenges

- Harsh environment (fly ash, high temperature, etc)
- Vibrations
- Robustness
- Ease of operation by plant staff
- Reliability

# VISION 21

## Energy Plant of the Future

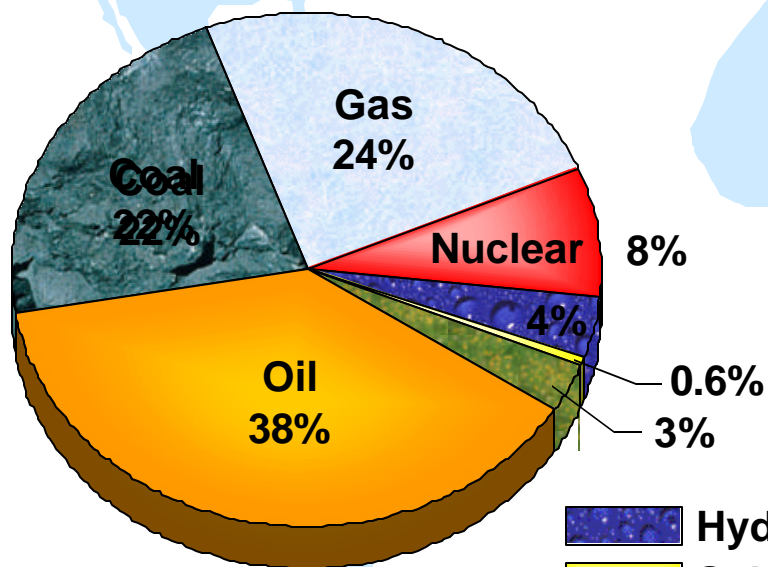


*National Energy Technology Laboratory*

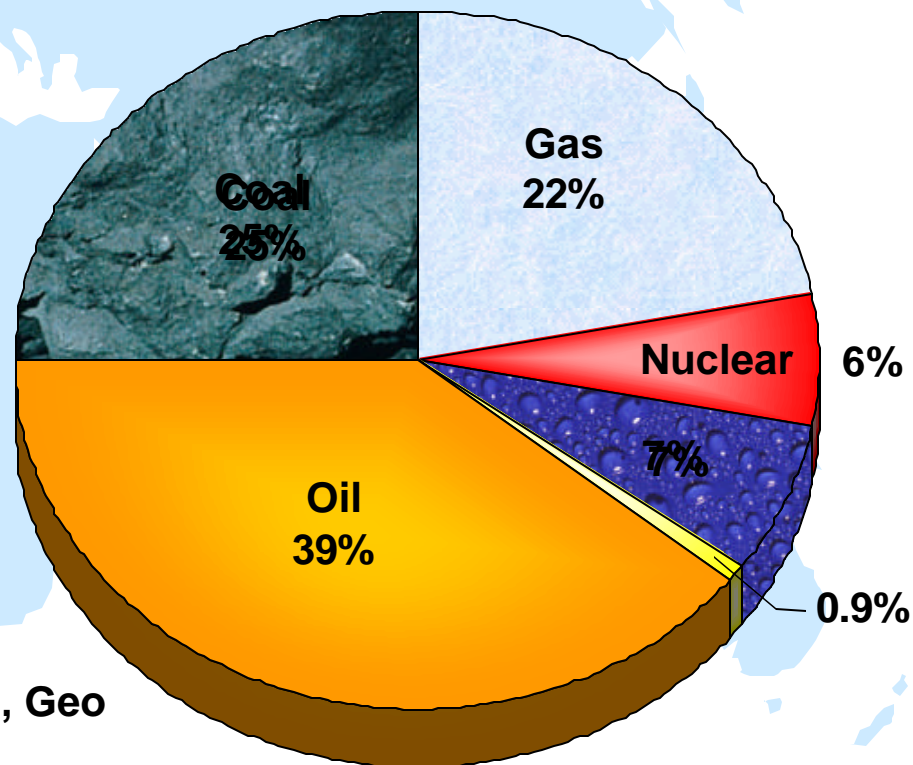


# Fossil Fuels Are the World's Dominant Energy Source

**United States**  
97 QBtu/yr; 85% Fossil Energy



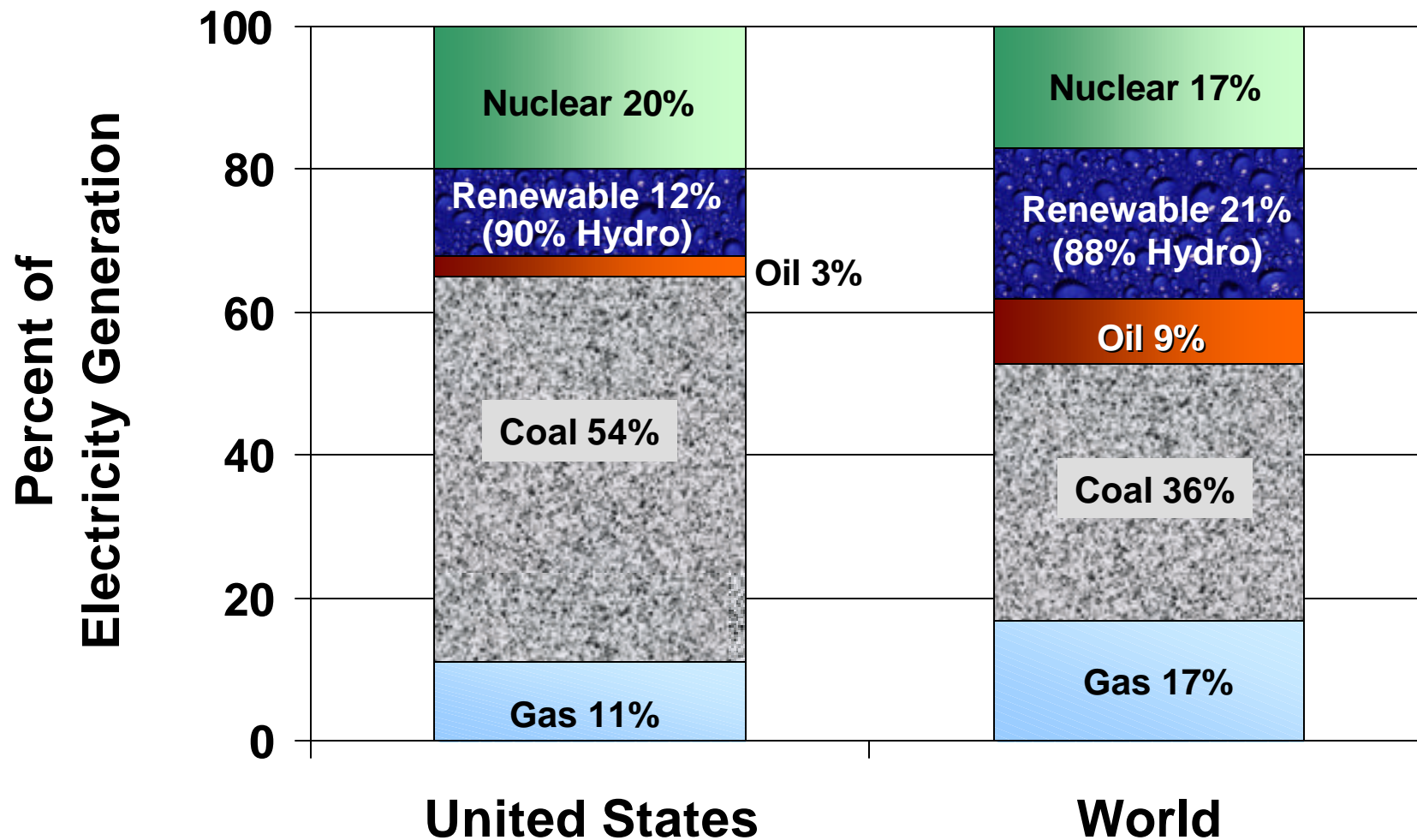
**World**  
380 QBtu/yr; 86% Fossil Energy



*World Data from EIA96. Does not include non-grid-connected biomass.  
U.S. Data from Table 2 of EIA REA 97 & AEO98 Table A2*

*Descriptor - include initials, /org#/date*

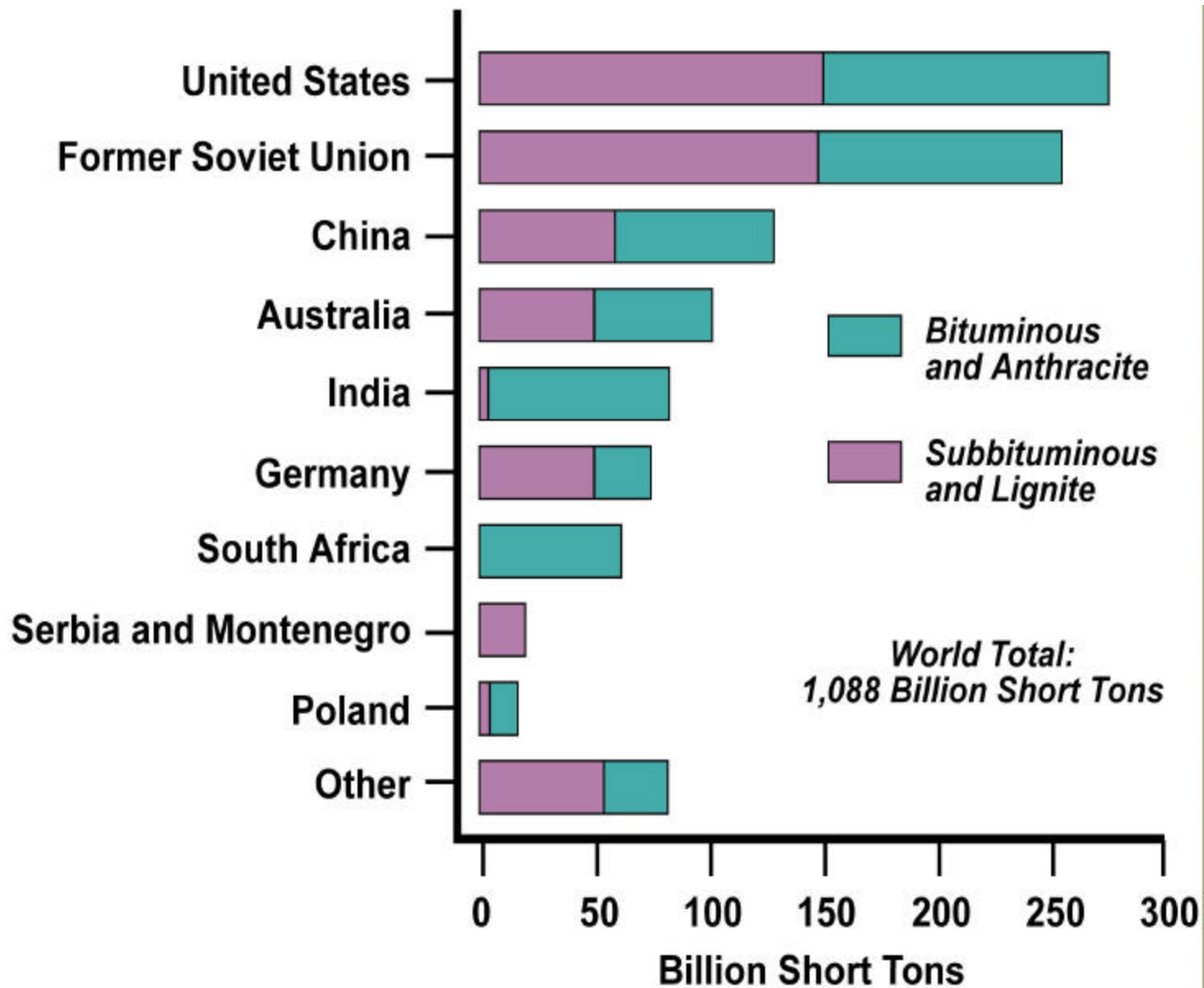
# Fossil Fuels Dominate Electricity Generation



*Data includes cogeneration. U.S. data is for fuel consumption for electricity  
World data: IEO 2000, Table 21  
U.S. data: AEO 2000, Table A2*

*Descriptor - include initials, /org#/date*

# World Recoverable Coal Reserves



# The Vision

**Effectively remove environmental concerns associated with the use of fossil fuels for producing electricity and transportation fuels (at competitive costs)**



# Drivers for Vision 21

- Recognition that fossil energy will be part of future energy mix
- Concern about environment, including global climate change
- Restructuring of energy industry
- Decreasing reserve margins and grid reliability issues
- Uncertain natural gas prices
- Recognition of value of “future options”

# The VISION 21 Program

## *The Program*

- Long-range, industry-driven R&D program to develop ultra-clean, fossil fuel-based energy plants
- Government/industry/academia cost-shared partnership
- Stresses technology innovation and a diverse mix of energy resources

## *The Challenge*

- Develop technology basis for Vision 21 energy plants with unprecedented efficiency and environmental performance
  - Focus on technology “modules”
  - Apply systems integration knowledge
  - Satisfy market needs



# Vision 21 Program Objectives

## Capital & Operating Costs/RAM

- Vision 21 must be competitive with other energy systems with comparable environmental performance

## Emissions

- $< 0.01 \text{ lb}/10^6 \text{ Btu}$   $\text{SO}_2$  and  $\text{NO}_x$
- $< 0.005 \text{ lb}/10^6 \text{ Btu}$  PM
- $< 1/2$  organic compounds in *Utility HAPS Report*
- $< 1 \text{ lb}/10^9 \text{ Btu}$  Hg

## Schedule of Benefits

- Technology spinoffs by 2005
- Designs for modules by 2012
- Commercial plant designs by 2015

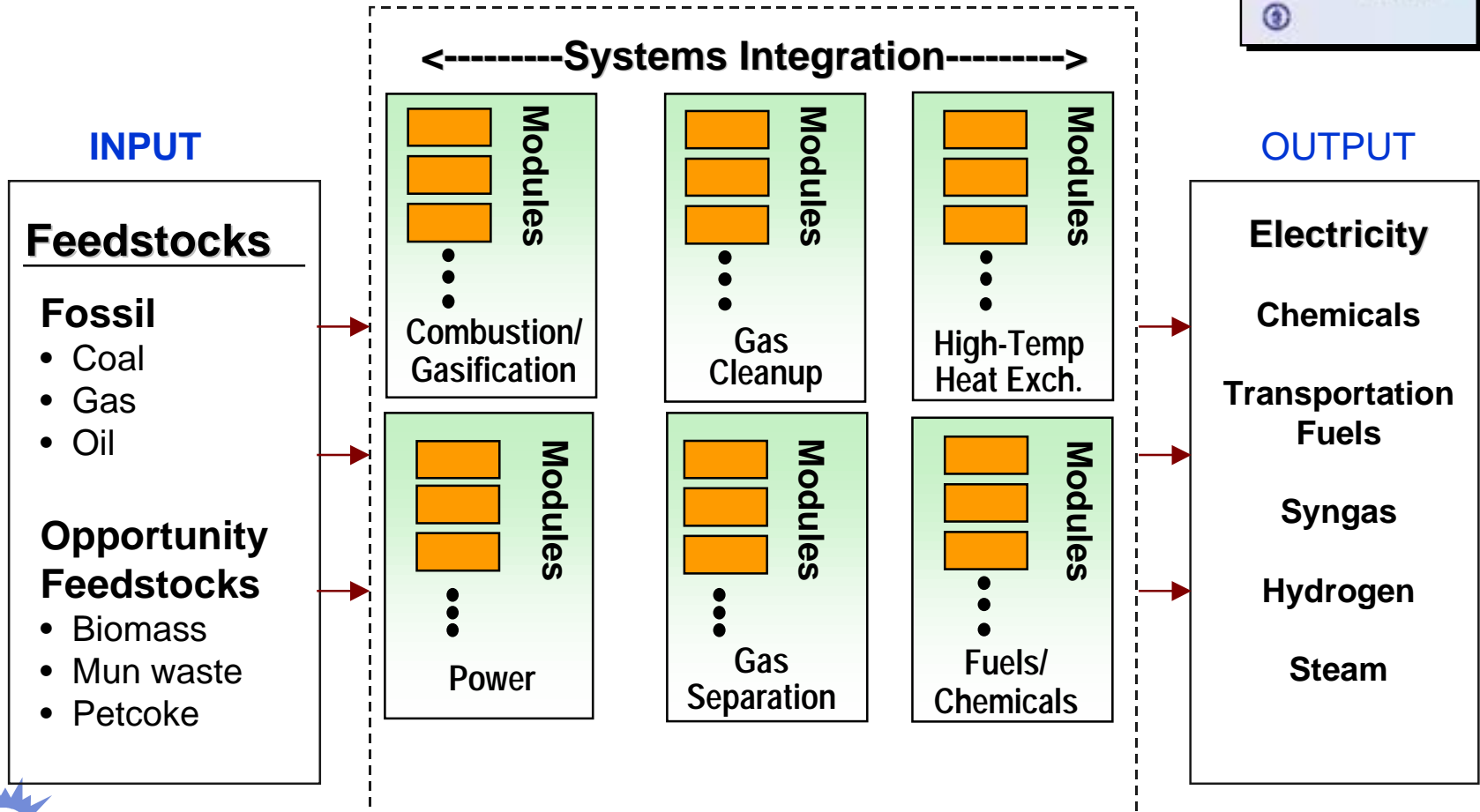
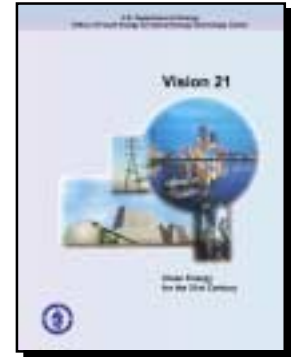
## Efficiency

- Electricity generation
  - coal based 60% (HHV)
  - gas based 75% (LHV)
- Fuels only plants 75% (LHV)

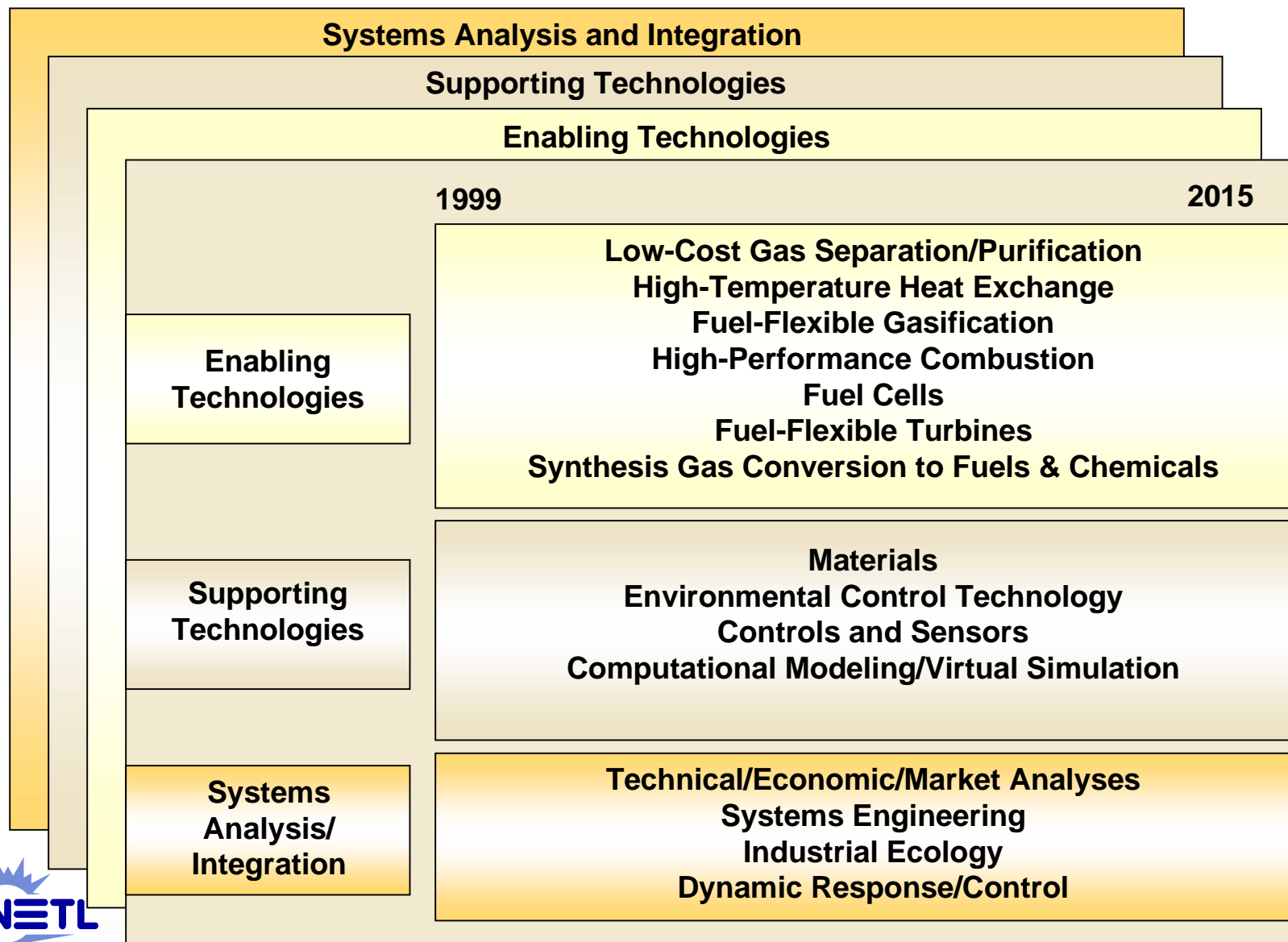


# VISION 21

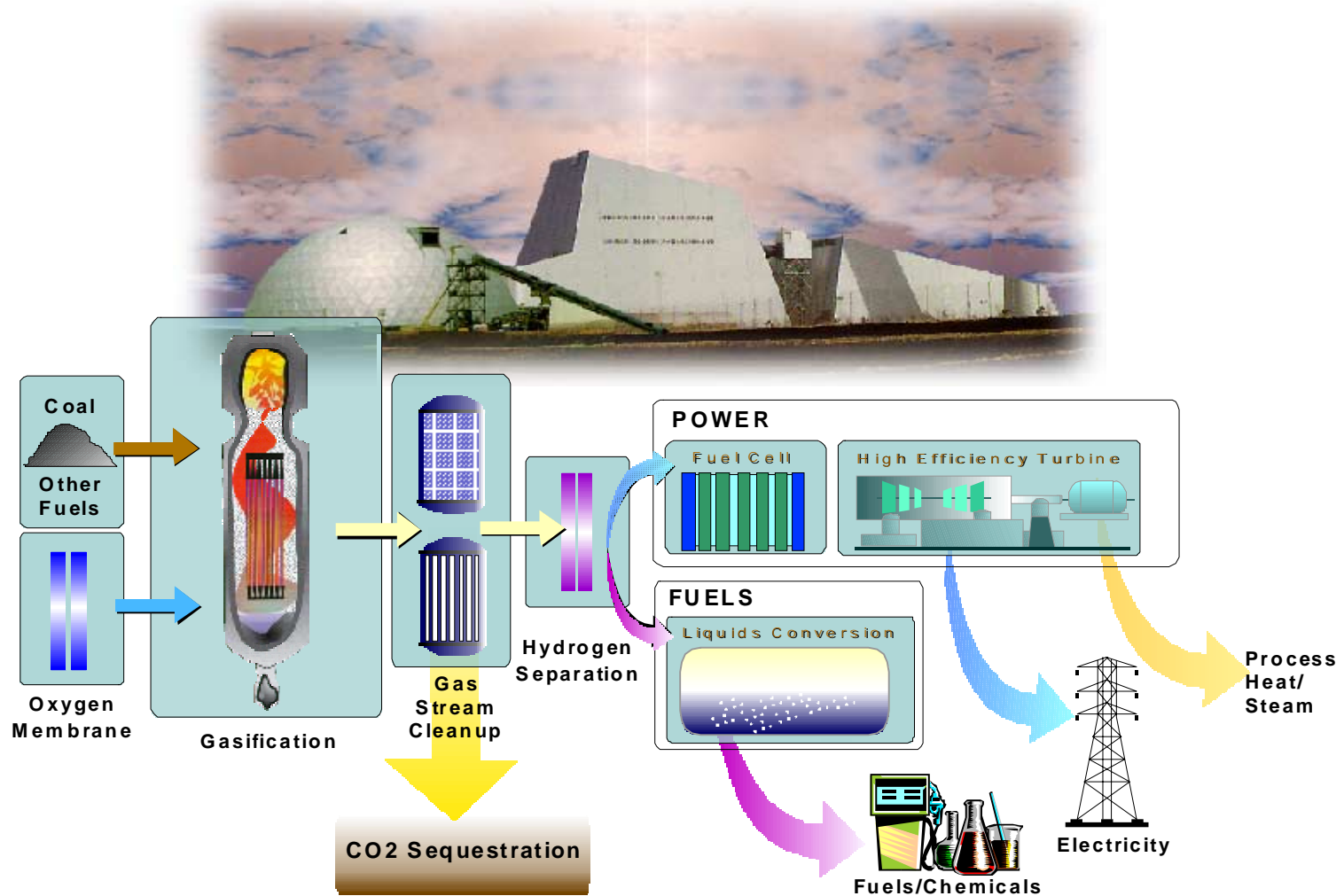
## Modular Technology



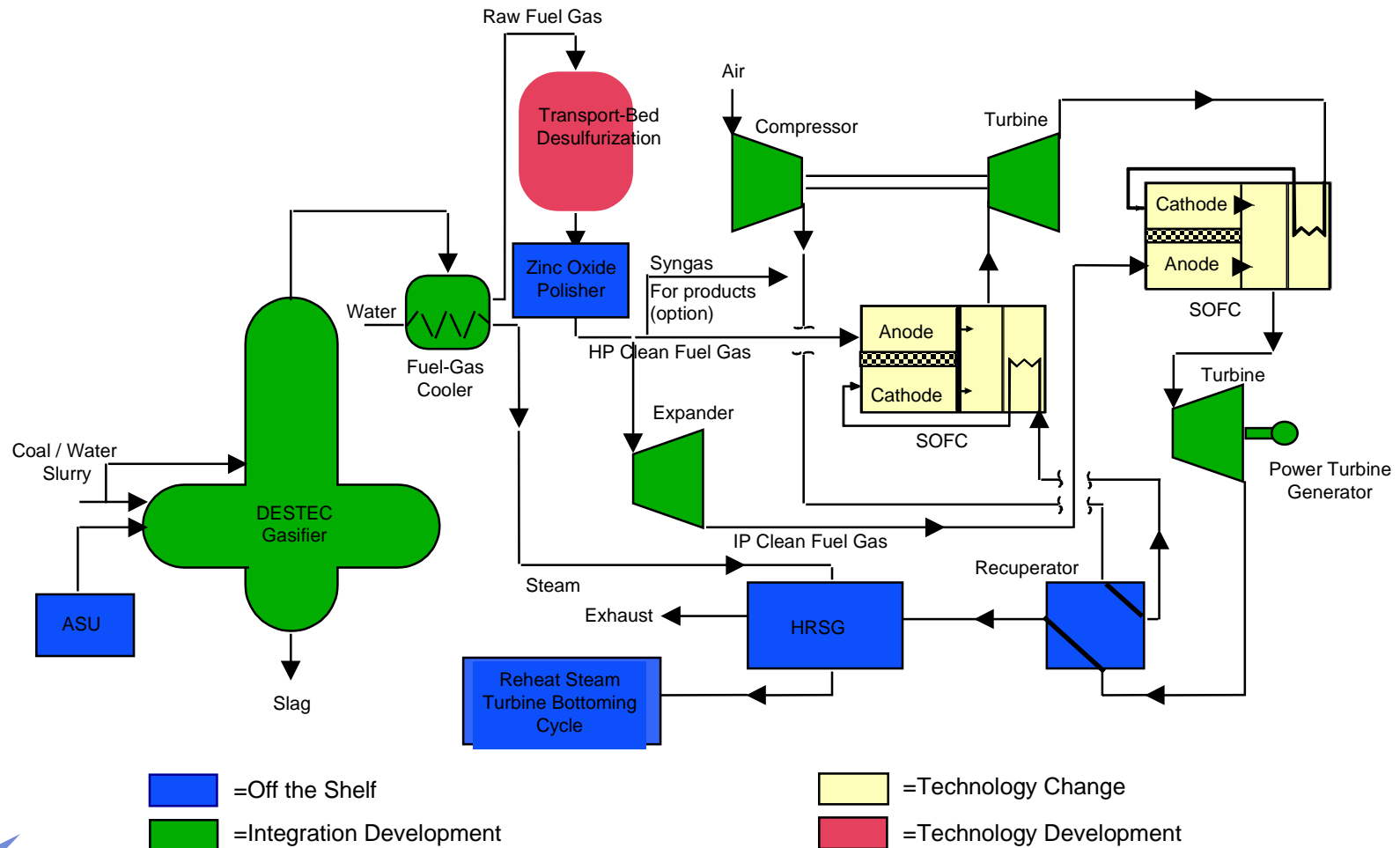
# VISION 21 Technology Roadmap



# VISION 21 ENERGY PLANT



# VISION 21 Fuel Cell/Gas Turbine Cycle



# VISION 21 Program

New Projects Contribute to the Ultra-Clean Energy Plant

**Virtual Simulation**

**Gasification & Combustion**

**Systems Integration**

**Advanced Materials**

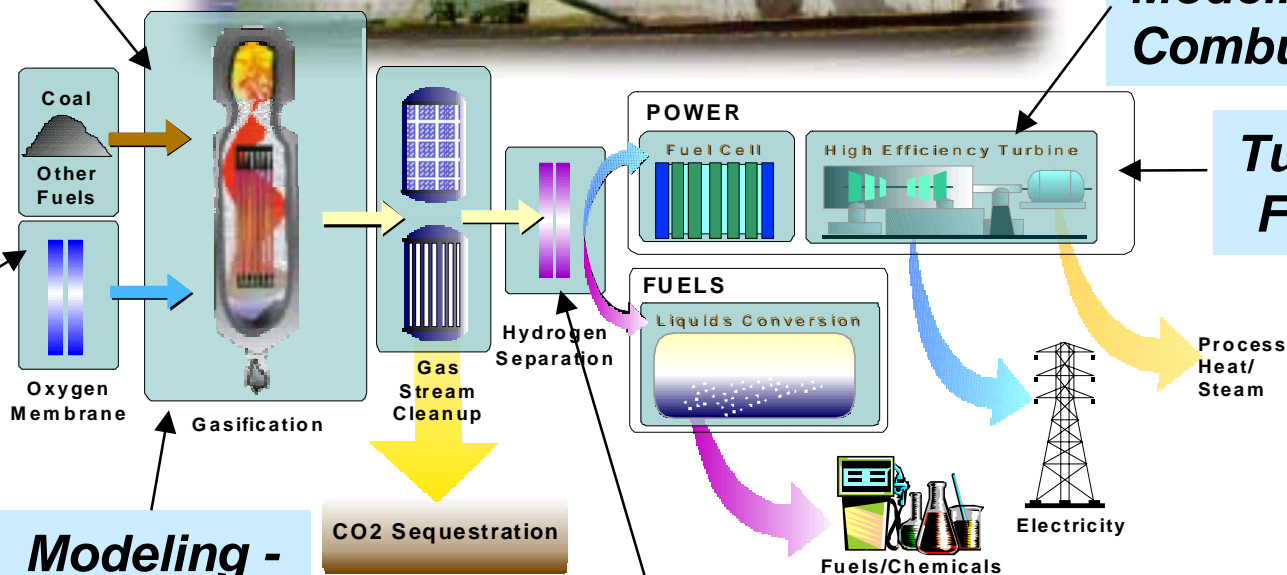
**Modeling - Combustion**

**Turbines & Fuel Cells**

**Oxygen Membrane**

**Modeling - Gas/Particle Flow**

**Hydrogen Membrane**



# New Projects Contribute to Ultra-Clean Energy Plant

- **Systems Integration**
  - National Fuel Cell Research Center
- **Computational Modeling & Virtual Simulation**
  - Reaction Engineering International
  - Fluent, Inc.
  - Princeton University
  - CFD Research Corp.
- **High-Temperature Materials**
  - Huntington Alloys
- **Gasification & Combustion**
  - Foster Wheeler
  - GE Energy and Environmental Research Corporation
  - Clean Energy Systems
- **Turbines & Fuel Cells**
  - Fuel Cell Energy
- **Advanced Separation Technology**
  - Siemens Westinghouse
  - Eltron Research
  - ITN Energy Systems



# What's Different About VISION 21?

## *Traditional Coal Plant*

- Based on single technology
- Emission control “added on”
- Produces electricity only
- Single point design
- Reliability by overdesign
- Simple controls

## *Vision 21*

- 
- Integrates multiple technologies
  - Industrial ecology
  - Multiple products
  - Defined design range
  - Reliability by smart design
  - Sophisticated controls

# VISION 21

**“The goals for the Vision 21 Program are very ambitious. If these goals can be achieved, Vision 21 technologies would offer the United States, and the world, a new method of coal-based power generation that would have significant advantages over current methods.”**

***National Research Council***



# What's Important?

- Leapfrog performance improvement
- Near-zero environmental impact
- Zero CO<sub>2</sub> emission option
- Feedstock and product flexibility
- Industrial ecology
- Technology development focus
- Systems integration



# TECHNOLOGY AREA: Sensors and Controls

Technology	Vision 21 Performance Objectives	Vision 21 Cost Objectives	Current Technology Performance	Current Technology Cost
Sensors	<ul style="list-style-type: none"> <li>Sensors to understand component performance, real-time plant performance, and the “health of plant equipment</li> <li>Sensors to support condition monitoring, non-destructive testing, and predictive maintenance tools</li> </ul>	<ul style="list-style-type: none"> <li>Cost of sensors for condition monitoring and specific unit operation control is integral with the technology module cost</li> <li>Cost of sensors for integrated plant operation is part of instrumentation and control. A reference I&amp;C cost objective for an oxygen blown gasification plant for power generation is \$35/kW</li> </ul>	<ul style="list-style-type: none"> <li>Most power plants are not equipped with state-of-the-art sensing capability – on-line analyzers for performance, condition monitoring measurements</li> <li>Sensors not currently available to meet Vision 21 plant needs</li> </ul>	<ul style="list-style-type: none"> <li>N/A</li> </ul>
Controls	<ul style="list-style-type: none"> <li>Information technology systems that permit real-time management of the power plant asset</li> <li>Closed loop process optimization</li> </ul>	<ul style="list-style-type: none"> <li>See above for cost perspective</li> </ul>	<ul style="list-style-type: none"> <li>PC based process control technology entering power plants</li> <li>Some open-loop process optimization (“advisory”)</li> </ul>	<ul style="list-style-type: none"> <li>Estimated I&amp;C cost for oxygen blown IGCC plant of \$40-50/kW</li> </ul>



# TECHNOLOGY AREA: Sensors and Controls

Technology	Barriers	Current Status	Approach 0-5 yrs	Approach 5-10 yrs	Approach 10-15 yrs
Sensors: Program considerations	<p><i>Program and Support Barriers</i></p> <ul style="list-style-type: none"> <li>Fragmented markets for advanced sensors resulted in inadequate private support for development efforts.</li> <li>Conventional thinking tends to treat sensors as an add on in the design stage and failed to recognize the roles advanced sensors can play. (Sensors should be an integral part of design)</li> </ul>	<ul style="list-style-type: none"> <li>Process developers consider sensors as an afterthought                             <ul style="list-style-type: none"> <li>Plan to utilize existing sensors rather than creating better ones</li> <li>Leads to increased process development cost</li> <li>Limits creativity and possible solutions.</li> </ul> </li> <li>Mismatch between current sensor capabilities and envisioned control requirements (e.g. speed and sensitivity)</li> </ul>	<p>YEARS 0-1</p> <ul style="list-style-type: none"> <li>Initiate an independent sensor development program to address known shortcomings.</li> </ul> <p>Focused workshop to identify sensor needs and requirements</p> <p>YEARS 0-3</p> <ul style="list-style-type: none"> <li>Extend sensor development program to meet defined needs                             <ul style="list-style-type: none"> <li>Model component and system performance to permit selection of measurement needs</li> <li>Assess state-of-the-art of sensors and identify gaps</li> <li>Define program, prepare solicitations, etc.</li> </ul> </li> </ul> <p>YEARS 3-5</p> <ul style="list-style-type: none"> <li>Perform program</li> </ul>	<ul style="list-style-type: none"> <li>Follow-up with workshops, communication between developers and users, and program support</li> <li>Monitor component and plant needs and revise priorities based on review of needs</li> <li>Demonstrate new sensors technology in operating plants</li> </ul>	<ul style="list-style-type: none"> <li>Continue follow-up activities</li> <li>Demonstrate new sensors technology in Vision 21 plant projects</li> <li>Support Vision 21 plant design and operation activities</li> <li>Assess the payback from DOE's sensors and control programs</li> </ul>



# TECHNOLOGY AREA: Sensors and Controls

Technology	Barriers	Current Status	Approach 0-5 yrs	Approach 5-10 yrs	Approach 10-15 yrs
Sensor Technology	<p><i>General Technical Barriers</i></p> <ul style="list-style-type: none"> <li>Limited and constrained accessibility to utilize sensors</li> <li>Harsh operating conditions</li> <li>Material limitations</li> </ul>	<p><i>Existing sensors have many limitations:</i></p> <ul style="list-style-type: none"> <li>Inadequate reliability, sensitivity, inaccuracy</li> <li>Slow response</li> <li>Complex and costly</li> <li>Single point and single phase</li> </ul> <p><i>Promising, but underdeveloped concepts exist, e.g. wave technologies</i></p> <p><i>Significant development required for each technology</i></p>	<ul style="list-style-type: none"> <li>Focus on in-situ, real time, fast response, field hardened, miniaturized sensors suitable for control (Interrogate and sense with energy only) potentially attainable with wave technologies                             <ul style="list-style-type: none"> <li>Optics</li> <li>Acoustics</li> <li>Electromagnetics</li> </ul> </li> <li>Develop sensors based on new concepts and using new technologies including nano-technology, MEM, etc.</li> </ul>	<ul style="list-style-type: none"> <li>Continue supporting development of sensors based on new concepts</li> <li>Test new sensors in operating plant environment</li> <li>Incorporate new sensors into new control systems</li> </ul>	<ul style="list-style-type: none"> <li>Continue supporting development and testing of new sensors</li> <li>Demonstration projects</li> </ul>

# TECHNOLOGY AREA: Sensors and Controls

Technology	Barriers	Current Status	Approach 0-5 yrs	Approach 5-10 yrs	Approach 10-15 yrs
Sensor Technology (continued)		<p><i>NETL Initiatives</i></p> <ul style="list-style-type: none"> <li>Sensors for physical properties (T,P, flow, etc.): High temperature sensors and measurement development using infrared technology, coating, etc. is currently supported by NETL. This effort will help improve efficiency and performance in combustion and gasification.</li> <li>Sensors for chemical species including emissions sensors: <ul style="list-style-type: none"> <li>NETL supported Sensors Research Corporation in developing advanced solid state sensors for measuring H<sub>2</sub>S, NO<sub>x</sub>, SO<sub>x</sub>, and NH<sub>3</sub></li> <li>NETL has an active program of mercury measurement, and this R &amp;D has laid a foundation for sensor development</li> </ul> </li> <li>Particulate sensors: Off-line and batch</li> <li>Facilities Diagnostics and maintenance sensors:</li> </ul>	<ul style="list-style-type: none"> <li>Continue current program initiatives e.g. test high temperature sensors, in-line testing of SRC chemical sensing technology</li> <li>Continue near term work using existing wave technology in extractive or bypass configurations</li> <li>Identify/evaluate applications for other emerging sensing technologies</li> </ul>	<ul style="list-style-type: none"> <li>Continue supporting development of sensors based on new concepts</li> <li>Test new sensors in operating plant environment</li> <li>Incorporate new sensors into new control systems</li> </ul>	<ul style="list-style-type: none"> <li>Continue supporting development and testing of new sensors</li> <li>Demonstration projects</li> </ul>



# TECHNOLOGY AREA: Sensors and Controls

Technology	Barriers	Current Status	Approach 0-5 yrs	Approach 5-10 yrs	Approach 10-15 yrs
Controls	<ul style="list-style-type: none"> <li>Developing advanced controls is under-funded compared to other areas</li> <li>Some hardware has long response time such as valves</li> <li>Knowledge of failure modes and operability problems needs to be improved</li> <li>Knowledge of some processes such as NO<sub>x</sub> generation and destruction, fate of trace elements, and predictive modeling need to be improved</li> </ul>	<ul style="list-style-type: none"> <li>Generic NO<sub>x</sub> Control Intelligent System (GNOCIS) developed by Southern Company Services under NETL funding using neural net based control technology lowers NO<sub>x</sub> emissions while maintaining plant performance</li> <li>Point solutions are being (have been) developed for specific (currently available) systems</li> <li>Some dynamic process simulators are available such as used on gasification, fuel cell, and hybrid systems</li> <li>Advanced process controls for other applications are well developed (e.g. automobiles)</li> </ul>	<ul style="list-style-type: none"> <li>Define process control needs required to meet the performance and reliability objectives for Vision 21 plants</li> <li>Evaluate state-of-the-art control technologies: Example control technologies to be reviewed include Regulatory Control Algorithm, Supervisory Optimization, Control Numerical Methods, Inferential Sensing, and Predictive Maintenance</li> <li>Define program to meet Vision 21 plant objectives – coordinate with component technology initiatives</li> <li>Direct plant and component development programs toward intelligently controllable systems (example: automotive engines)</li> <li>Identify key data and models, and components in control systems required to develop advanced control strategies</li> <li>Implement programs to show benefit of advanced controls and predictive maintenance</li> </ul>	<ul style="list-style-type: none"> <li>Direct development of components and plants to leverage advanced control and predictive maintenance</li> <li>Update program to reflect new plant needs and technology development</li> <li>Implement program</li> <li>Continue review of Vision 21 plant needs and monitoring control technology state-of-the-art</li> </ul>	<ul style="list-style-type: none"> <li>Demonstrate innovative process control technologies</li> </ul>



# VISION 21 Projects

## *Gasification and Combustion*

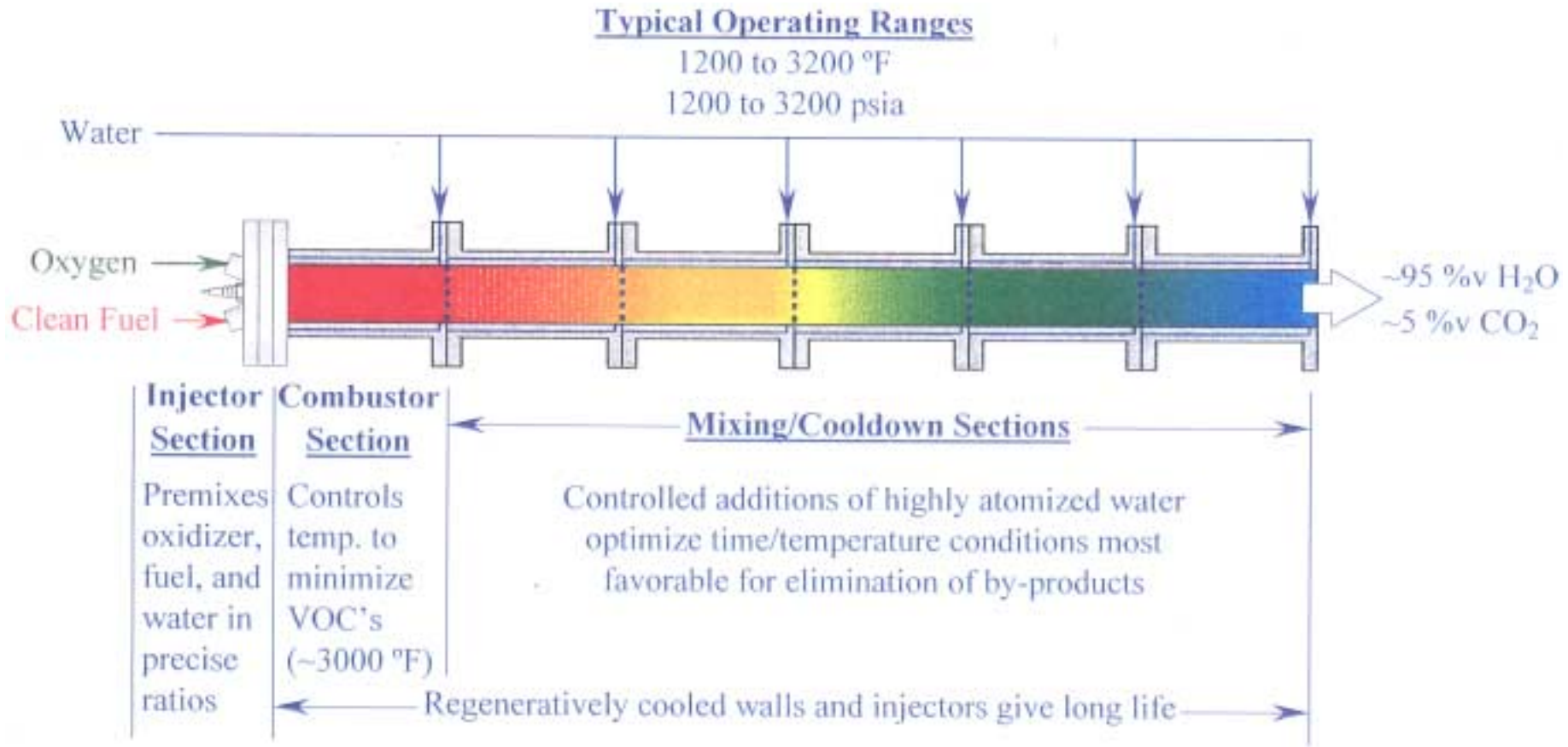
***Clean Energy Systems***  
*(Sacramento, CA)*



***“Rocket engine” steam generator to power an advanced turbine, generating electricity and emitting only water and a stream of CO<sub>2</sub> ready for sequestration***



# The “*Rocket Engine*” Steam Generator



*Clean Energy Systems*

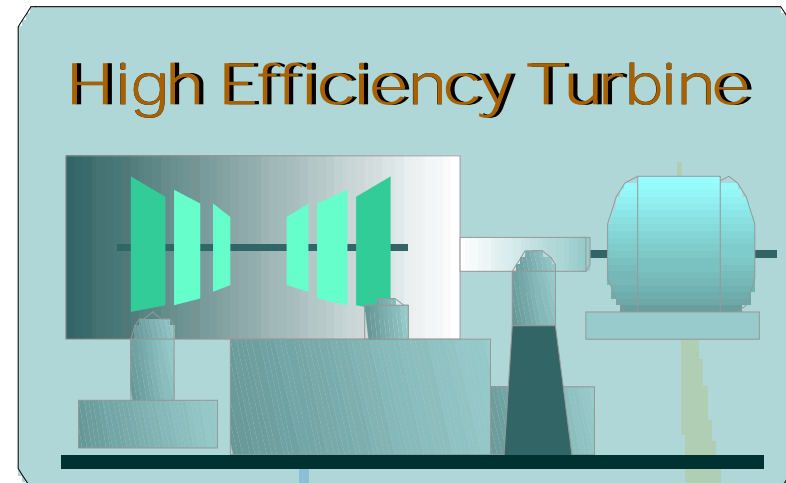
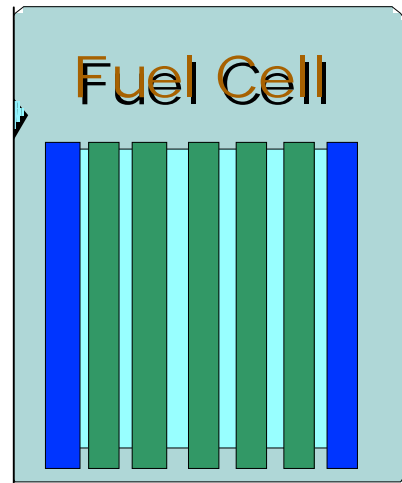


# VISION 21 Projects

## *Turbines & Fuel Cells*

***Fuel Cell Energy*** (Danbury, CT)  
Capstone Turbine (Woodland Hills, CA)

*Fuel cell/gas turbine “hybrid” power system with 65-80% efficiency*



# Gasification and Combustion

## ***Foster Wheeler Development Corporation***

*(Livingston, NJ)*

Nexant

*(San Francisco, CA)*

Praxair

*(Danbury, CT)*

REI

*(Salt Lake City, UT)*

Corning

*(Elmira, NY)*

ADA Technology

*(Livermore, CA)*

## ***GE Energy & Environmental Research Corporation***

*(Irvine, CA)*

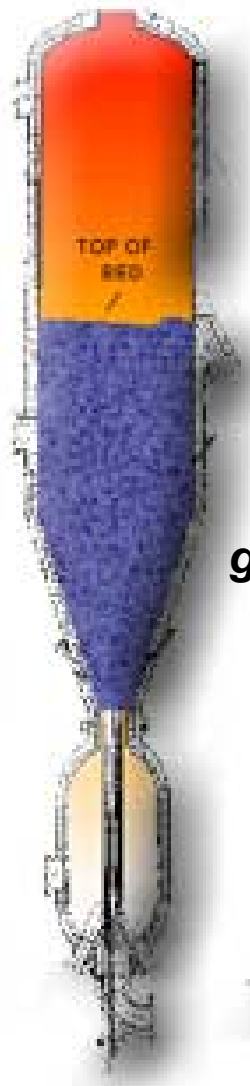
Southern Illinois University

*(Carbondale, IL)*

California Energy Commission

*(Sacramento, CA)*

***Advanced combustion/  
gasification concept that produces  
hydrogen for fuel cells or  
combustion turbines and  
sequestration-ready CO<sub>2</sub>***



***Pressurized circulating fluidized  
bed partial gasification module  
that produces gaseous and  
solid fuels for use in fuel-flexible  
high-efficiency plants***



image courtesy of Foster Wheeler

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